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Introduction: Exposure to 35,000 ft without preoxygenation, breathing 100% oxygen prior to decompression, can result in severe decompression sickness (DCS). Exercise while decompressed increases the incidence and severity of symptoms. Clarification of the level of activity versus time to symptom onset is needed to refine recommendations for current operations requiring 35,000-ft exposures. Currently, the USAF limits these operations to 30 min following 75 min of preoxygenation. The objective of this study was to determine the effect of exercise intensity on DCS incidence and severity at 35,000 ft. Methods: Following 75 or 90 min of ground-level preoxygenation, 54 male and 38 female subjects were exposed to 35,000 ft for 3 hours while performing strenuous exercise, mild exercise, or seated rest. The subjects were monitored for venous gas emboli (VGE) with an echo-imaging system and observed for signs and symptoms of DCS. Results: Exposures involving strenuous and mild exercise resulted in higher incidence ($P < .05$) and earlier onset of symptoms ($P < .05$) of DCS than exposure at rest. Mild and strenuous exercise during exposure did not differ in incidence or rate of onset. Incidence at 30 min of exposure was 8% at rest and 23% while exercising. Conclusion: The results showed that current guidelines for 35,000-ft exposures keep DCS risk below 10% at rest. Exercise, even at mild levels, greatly increases the incidence and rate of onset of DCS.						
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ORIGINAL RESEARCH

The Effect of Exposure to 35,000 ft on Incidence of Altitude Decompression Sickness

JAMES T. WEBB, PH.D., KEVIN M. KRAUSE, PH.D.,
ANDREW A. PILMANIS, PH.D., MICHELE D. FISCHER, B.S.,
AND NANDINI KANNAN, PH.D.

WEBB JT, KRAUSE KM, PILMANIS AA, FISCHER MD, KANNAN N. *The effect of exposure to 35,000 ft on incidence of altitude decompression sickness*. Aviat Space Environ Med 2001; 72:509-12.

Introduction: Exposure to 35,000 ft without preoxygenation (breathing 100% oxygen prior to decompression) can result in severe decompression sickness (DCS). Exercise while decompressed increases the incidence and severity of symptoms. Clarification of the level of activity vs. time to symptom onset is needed to refine recommendations for current operations requiring 35,000-ft exposures. Currently, the U.S. Air Force limits these operations to 30 min following 75 min of preoxygenation. The objective of this study was to determine the effect of exercise intensity on DCS incidence and severity at 35,000 ft. **Methods:** Following 75 or 90 min of ground-level preoxygenation, 54 male and 38 female subjects were exposed to 35,000 ft for 3 h while performing strenuous exercise, mild exercise, or seated rest. The subjects were monitored for venous gas emboli (VGE) with an echo-imaging system and observed for signs and symptoms of DCS. **Results:** Exposures involving strenuous and mild exercise resulted in higher incidence ($p < 0.05$) and earlier onset of symptoms ($p < 0.05$) of DCS than exposure at rest. Mild and strenuous exercise during exposure did not differ in incidence or rate of onset. Incidence at 30 min of exposure was 8% at rest and 23% while exercising. **Conclusion:** The results showed that current guidelines for 35,000-ft exposures keep DCS risk below 10% at rest. Exercise, even at mild levels, greatly increases the incidence and rate of onset of DCS.

Keywords: altitude, DCS, VGE, emboli, decompression sickness, exercise, denitrogenation, preoxygenation, prebreathe.

THE POTENTIAL for development of altitude decompression sickness (DCS) during 35,000-ft airdrop missions conducted by the U.S. Air Force (USAF) has been largely avoided by restricting time of exposure to no more than 30 min and requiring 75 min of preoxygenation (1). An airdrop is dependent on many factors; e.g., weather, aircraft and personal equipment, and mission timing. Variation in these and other factors could delay the airdrop following decompression of the aircraft and extend the duration of exposure. It would benefit the airdrop community to know the change in DCS risk caused by extending the exposure time beyond 30 min.

Extensive research on DCS risk at 35,000 ft was accomplished during World War II (3,5,10,15). Gray (5) reported that a 4-h exposure to 35,000 ft without prebreathing produced 30% DCS and required descent due to symptom severity. This level of symptom severity is equivalent to a Grade 4 DCS joint pain (13) and is much more severe than currently used by the USAF to termi-

nate exposures. Stewart and Smith (10) reported that 3-h resting exposures to 35,000 ft without prebreathing resulted in 51% DCS symptoms (Fig. 1).

The criteria for determining if a sign or symptom is actually DCS have changed since World War II (13). Reports of higher levels of DCS in recent years are a reflection of lowered levels of pain or prominence of other signs and symptoms required for declaration of DCS. These changes are consistent with the increased level of vigilance required of current aviators and the recognition that relatively mild symptoms may result in distraction effecting crewmember performance.

Previous studies at this institution have shown that increasing altitude of exposure following 1 h of preoxygenation produces both higher levels of DCS and shorter time to symptom development (11). Since the maximum altitude during these studies was 30,000 ft and the World War II data indicated relatively high levels of DCS at 35,000 ft and 38,000 ft relative to 30,000 ft, a need was evident for DCS risk data at 35,000 ft using current symptom definitions.

One of the variables in determining DCS risk is the activity level of individuals involved in the mission; e.g., aircrew in the cockpit, loadmasters coordinating the airdrop, and the jumpers. Level of exercise is of considerable importance in determining DCS risk (6,8), however, the effect of increasing altitude of exposure from 30,000 ft to 38,000 ft produced a larger increase in DCS incidence than doubling the level of exercise at either altitude (2). Ferris et al. (3) found that seated rest at 35,000 ft without preoxygenation was as effective at

From the Air Force Research Laboratory, AFRL/HEPR, High Altitude Protection Research at Brooks AFB, San Antonio, TX (A. A. Pilmanis); Wyle Laboratories, Life Sciences, Systems, and Services (J.T. Webb, K.M. Krause, and M.D. Fischer); Division of Mathematics and Statistics, University of Texas at San Antonio (N. Kannan). Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Air Force.

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Address reprint requests to: James T. Webb, Ph.D. (Lead Scientist, Wyle Laboratories, Life Sciences, Systems, and Services), 13818 Chittim Oak, San Antonio, TX 78232; james.webb@brooks.af.mil

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preventing DCS as 2 h of preoxygenation prior to an exercising exposure to 35,000 ft. A 4-h preoxygenation provided complete protection for 10 of 12 subjects exposed to 35,000 ft while exercising. In another test with 7 exercising subjects at 35,000 ft, 8 h of preoxygenation provided complete protection from DCS (3). Fulton (4) reviewed the effects of rest vs. exercise (5 deep knee bends every 3 min) during zero-prebreathe exposures to 35,000 ft and showed 55% DCS incidence in 90 resting subjects and 100% DCS in 158 exercising subjects. The mean time to DCS in that study was 61 min while at rest and 16 min while exercising. With 4 h of prebreathe, the incidence of DCS was reduced to 55% in the exercising group. Morgan et al. (7) reported development of DCS in 3 of 8 resting subjects exposed to 33,500 ft following at least 2 h of 100% oxygen prebreathe, despite exclusion of subjects with "a history of dysbarism."

The current study will provide information on risk and effect of exercise using the current test termination criteria. Data on venous gas emboli (VGE) were unavailable during the World War II studies because the equipment for non-invasive measurement of VGE was not developed until the 1970's. During the current study, the data on VGE were collected to provide additional information about exposure severity in addition to observed or reported DCS symptoms. Although the incidence and severity of VGE have not been shown to correlate well with DCS on an individual predictive basis, the population response to increased altitude exposure severity, has been documented (Webb et al., 1998). The information provided by this study could be used to verify or recommend changes to existing USAF policy.

METHODS

The voluntary, fully informed consent of the subjects used in this research was obtained in accordance with AFI 40-402. All subjects passed an appropriate physical examination and were representative of the USAF-rated aircrew population. They were not allowed to participate in SCUBA diving, hyperbaric exposures, or flying for at least 48 h before each scheduled altitude exposure.

Prior to each 3-h altitude exposure, a physician conducted a short physical examination of subjects to iden-

TABLE I. VGE AND DCS RESULTS VS. ACTIVITY AND PREOXYGENATION CONDITIONS DURING 3-H, 35,000-FT EXPOSURES.

Activity	Preoxygenation, min	Subjects	% VGE	% DCS
Seated	75	30 males	63	63
		30 females	40	50
		combined total	52	57
Mild	90	24 males	83	88
		8 females	75	100
		combined total	81	91
Strenuous	75	30 males	93	93
		30 females	73	100
		combined total	83	97

tify any signs of illness or other problem that would endanger the subject or bias the experimental results. Breathing gas during preoxygenation and while decompressed was 100% oxygen (aviator's breathing oxygen; normal analysis 99.7–99.8% oxygen). The 75-min prebreathe exposures were accomplished during an earlier protocol wherein chamber ascent and descent were at a rate not exceeding 5,000 fpm from ground level pressure to 20,000 ft and at a rate not exceeding 10,000 fpm from 20,000 ft to 35,000 ft. In a follow-on effort to reduce the high incidence of DCS observed when strenuous exercise was performed, we reduced the level of exercise to mild, increased the prebreathe time to 90 min, and reduced the ascent and descent rates to 5,000 fpm above 20,000 ft. A neck-seal respirator made by Inter-technique (Plaisir Cedex, France) was used to deliver oxygen. This mask provided a slight (2-cm of water) positive pressure which reduced the opportunity for inboard leaks of nitrogen from the atmosphere and was more comfortable than the standard aviator's mask.

At 10–15 min intervals, the subjects were monitored for VGE using a Hewlett Packard Sonos 1000 Doppler/Echo-Imaging System. This system permits both audio and visual monitoring and recording of gas emboli in all four chambers of the heart. VGE were graded using a modified Spencer Scale (9).

Subjects were either seated at rest for the entire exposure or performed strenuous or mild exercise at intervals throughout the exposure. The strenuous exercise consisted of cycle ergometry at 60 rpm for 3 of every 10 min with a resistance of 2 kp. Walking to the Monarch 818E ergometer and echo-imaging station between periods of seated rest involved less than 10 steps in any direction. Mild exercise consisted of three upper-body exercises as described in Webb et al. (12). The subjects walked less than 10 steps between exercise stations and the echo-imaging station at 4-min intervals. Rest consisted of seated rest in an airline-type seat and involved no walking or standing. There were 30 male and 30 female subjects who performed strenuous exercise during one exposure and remained seated at rest for a second exposure, allowing matched controls for the effect of strenuous exercise and gender. There were 32 different subjects who were used for the exposures involving mild exercise (Table I). Minimum time be-

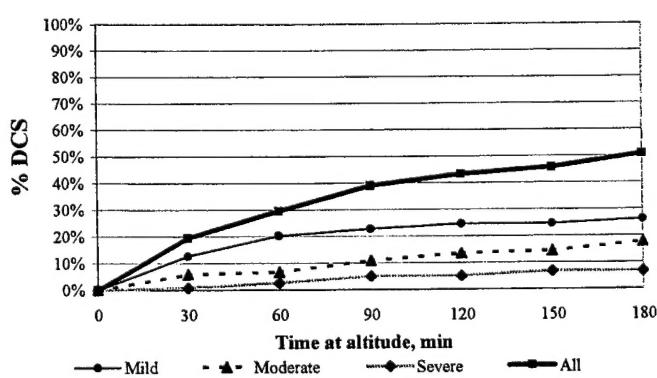


Fig. 1. Incidence of mild, moderate, and severe DCS as a function of 35,000-ft exposure duration (10)

tween exposures was at least 72 h, preferably 1 wk, and nominally 1 mo.

To quantify the level of effort required by each activity, ground-level metabolic data (oxygen uptake; $\dot{V}O_2$) were collected on five subjects not involved in the protocol, but representative of the subject population. To account for any cumulative effects, data were obtained for a period of 30–60 min while each subject rested or performed mild or strenuous exercise as previously described. The $\dot{V}O_2$ results from a SensorMedics 2900z (Yorba Linda, CA) metabolic measurement system were compared using a one way repeated measures analysis of variance. During seated rest, the mean $\dot{V}O_2$ was $3.9 \pm 0.3 \text{ ml oxygen} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Mild exercise required $6.5 \pm 0.4 \text{ ml oxygen} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and what we define as strenuous exercise required $12.4 \pm 1.4 \text{ ml oxygen} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, both significantly higher than rest and significantly different from each other ($p < 0.05$; Fig. 2).

Endpoints (test termination criteria) of the exposures were: 1) completion of the scheduled exposure (3 h); 2) development of Grade 2 DCS joint pain; or 3) development of DCS signs or symptoms other than joint pain. DCS joint pain was graded as follows: Grade 1 = intermittent, mild to moderate pain, intermittent or constant joint awareness or "fullness"; Grade 2 = constant, tolerable, mild to moderate pain (13). Subjects accomplished a 2-h post-breathe with 100% oxygen after recompression to ground level. Two subjects were referred to Hyperbaric Medicine for treatment of symptoms.

Table I shows the conditions of three experiments involving exposure to 35,000 ft. Log Rank and Wilcoxon's tests were used to compare homogeneity of curves representing cumulative incidence of DCS and VGE with the three levels of activity vs. time. A Chi Square test was used to compare mild exercise vs. either rest or strenuous exercise.

RESULTS

Since there was no difference in DCS incidence between the 84 male exposures and 68 female exposures (Chi Square = 0.21; $p = 0.65$; Table I), data from both groups were pooled to determine the effects of exercise

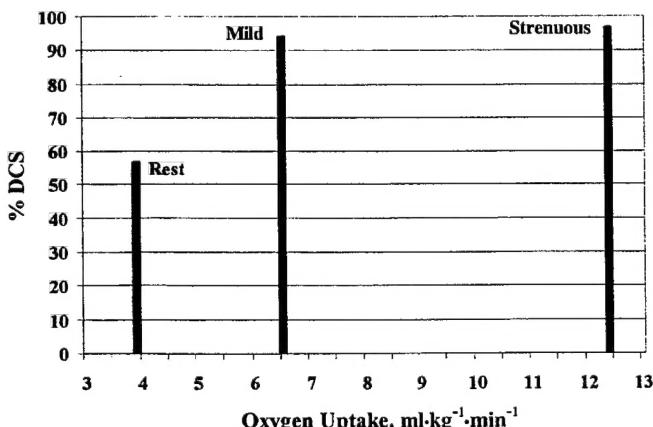


Fig. 2. Oxygen uptake vs. incidence of DCS. Note: The mean oxygen uptake was determined by measurement of oxygen consumption of five subjects representative of the subject population.

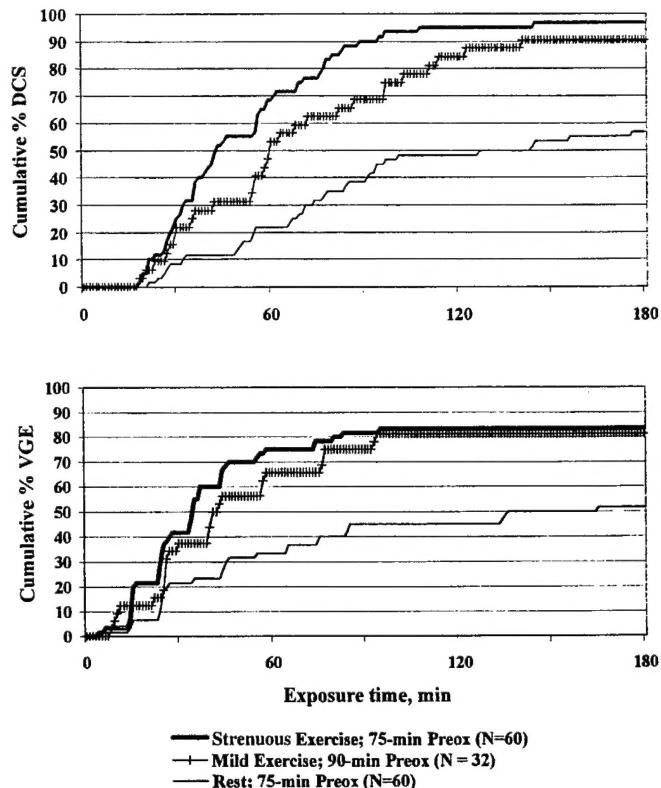


Fig. 3. Cumulative incidence of DCS and VGE. Note: Cumulative number of subjects who, up to each minute, had experienced DCS or VGE divided by the total number of subjects is depicted as Cumulative % DCS or VGE.

level on DCS incidence. Fig. 2 shows an abrupt increase in DCS with mild exercise ($p < 0.05$). The DCS incidence with strenuous exercise was not significantly different (Chi Square = 0.54; $p = 0.47$) than that with mild exercise (Fig. 2; Table I). DCS symptoms occur more rapidly with mild or strenuous exercise compared with symptom onset during rest ($p < 0.0001$; Fig. 3). There was no difference between DCS cumulative incidence curves for the two exercises ($p > 0.05$). The same statistical result was found with comparisons of VGE cumulative incidence curves. Of the 152 exposures reported here, 9 resulted in serious symptoms (neurologic and respiratory). Two required hyperbaric oxygen treatment to resolve and the other seven subjects' symptoms resolved before or during a 2-h post-breathe with 100% oxygen.

DISCUSSION

A 3-h resting exposure to 35,000 ft after a 75-min resting preoxygenation produces a relatively high incidence of DCS (57%). Performance of mild exercise results in 94% DCS (Fig. 2 and 3) and strenuous exercise results in 97% DCS. No difference was observed in the shape of the DCS or VGE incidence vs. exposure time curves between mild and strenuous exercise.

The very similar and rapid onset of VGE and DCS symptoms with mild and strenuous exercise as compared with rest implies that a relatively low level of exercise will produce a maximal effect on VGE and DCS incidence at 35,000 ft. The additional 15 min of preoxy-

genation prior to exposures with mild exercise did not provide increased protection. The left shift of the curve representing onset of VGE and symptoms (cumulative % DCS and VGE vs. time) with exercising vs. resting exposures follows the depiction by Webb and Pilmanis (14) and is in agreement with many studies of the effect of exercise on DCS (2–4,8).

Although the onset of DCS is more rapid at 35,000 ft than at lower altitudes with similar preoxygenation, the incidence of severe DCS symptoms was no higher during the current studies than during analogous studies at 30,000 ft (12). The results of exposures to 35,000 ft during World War II, during which severe symptoms were commonplace, were probably influenced by both shorter (or nonexistent) preoxygenation and termination criteria which allowed more severe symptom development prior to recompression (2,3,10,15). Severity of symptoms during the current studies was kept low due to rapid recompression at symptom onset which probably reduced progressive symptom development.

Another factor which may have kept the level and severity of symptoms lower than some of the World War II studies is the protocol-stipulated use of 100% oxygen as the breathing gas for 2 h after exposure; possibly reducing delayed or recurring DCS symptoms. Air was the breathing mixture following the World War II studies, even if symptoms developed during the exposure.

These findings reinforce the current USAF policy regarding exposure to 35,000 ft. The current 30-min limit on exposures to 35,000 ft following 75 min of preoxygenation has been shown to keep symptom level low, especially if no exercise is performed.

CONCLUSIONS

Incidence and onset of DCS at 35,000 ft reported in this study differ from World War II data in that current termination criteria revealed higher levels of symptom development early in the exposures. The effect of exercise on DCS incidence was a major factor under these conditions as even mild exercise produced a large increase in DCS incidence. Performance of strenuous vs. mild exercise did not appear to change either the final incidence or onset rate of symptom development. This information reinforces the existing 30-min limit of exposure to 35,000 ft following 75 min of preoxygenation and emphasizes the need to avoid exercise while decompressed. The consequence of exceeding 30 min of exposure, especially if exercising, is a rapid increase in DCS incidence.

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